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Jean-Claude Sureau	ATC-90

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16. Abstract

In current ATC radars, high altitude targets are at a disadvantage when competing with low altitude undesired returns such as ground clutter and birds. The "zoom antenna" technique is proposed as a means of virtually eliminating this problem. An implementation based on control of multiple elevation beams during each range sweep interval is recommended as applicable to both S-band and L-band ATC radars.

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1.0 INTRODUCTION

Present day ATC surveillance radars are two-dimensional systems which use fan beam antennas. The elevation pattern typically has a 3 dB beamwidth of several degrees and is "spoiled" for high angle coverage, typically 30 to 40 degrees (see Figure 1). The beam shaping is a compromise between providing high gain at low elevation angles for long range coverage and adequate gain at high elevation angles to maintain high altitude coverage at the shorter ranges. In older models, transmission and reception occur over the same beam while in more recent models a second receiver beam is available. This auxillary beam ("passive horn") is nearly identical in shape to the principal beam except that it is tilted up. It is activated during the early portion of a range sweep interval and is used primarily as a means of reducing the short range ground clutter.

However, even equipped with a modern signal processor, (See below*) a conventional fan system still has some deficiencies. The heart of the problem lies in the large variation in the two-way gain within the elevation sector, typically 30 dB for an Airport Surveillance Radar (ASR) and 20 dB for an Air Route Surveillance Radar (ARSR). This implies a large variation in the system performance as a function of elevation angle/altitude. Sources of undesired returns such as birds, rain clutter and ground clutter are enhanced with respect to high altitude desired targets. The use of Sensitivity Time Control (STC) to maintain a nearly constant minimum detectable signal (to eliminate birds for example) at lower altitudes will result in loss of coverage at high altitude. If allowed to be detected, these spurious targets are particularly troublesome in an automated system which must attempt to cope with a contaminated data base.

The most straightforward approach to the solution of the problem is to transmit and receive over a wide "flat top" sector, which retains sharp cut-off at the horizon to minimize ground clutter and multipath, together with an "R^4" STC. This system would provide constant sensitivity throughout the entire scan volume. Unfortunately, the resulting low antenna gain makes the system extremely wasteful of RF energy and consequently requires an intolerable high transmitter power.

* L. Cartledge and R. M. O'Donnell, "Description and Performance Evaluation of the Moving Target Detector," Project Report ATC-69, Lincoln Laboratory, M.I.T. (8 March 1977).
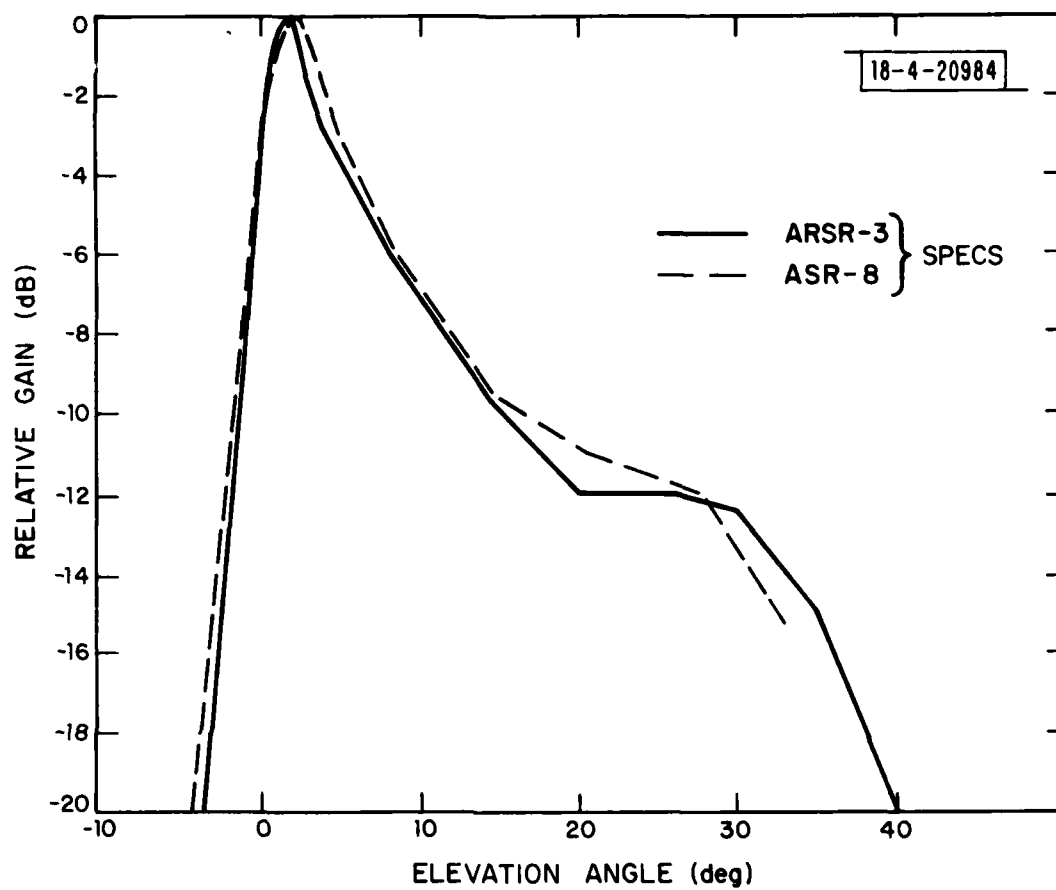
Fig. 1.   Typical ATC radars.

The solution which is proposed in this document, termed a "zoom antenna," represents a compromise in that it retains the energy efficiency of the current configuration but introduces additional complexity in the antenna. The "zoom" principle is described in Section 2 and two specific examples of implementation are described in Sections 3 and 4.

2.0 "ZOOM ANTENNA"

2.1 Principle

The "Zoom Antenna" is based on two observations. Firstly, the radar system operation is determined by the product of the transmit and receive patterns and that these two patterns need not be identical. Secondly, while the transmit is fixed during a range sweep interval since it is used only during the short period of time corresponding to the pulse length, the receive pattern need not be fixed. This latter point has already been exploited in systems using a "passive horn" and is based on the fact that there is a unique association between time and range within a sweep interval (PRI).

At any instant of time, the optimum two-way pattern (product of transmit and receive patterns) which leads to an altitude independent performance is depicted in Figure 2. Already this simplistic picture illustrate the principle of zoom which is simply a variation of the effective two-way beamwidth, or field-of-view during a range sweep interval. To retain high system energy efficiency, it is proposed that the desired two-way pattern be generated as depicted in Figure 3. The transmit pattern (Figure 3a) retains its shape as a basically narrow beam which has been spoiled so as to reach a plateau up to the maximum desired coverage angle. The bulk of the "zoom" operation is confined to the receive pattern (Figure 3b) which is varied (in principle continuously, in practice in discrete steps) within the range sweep. Note that not only is the beamwidth varied but also that the shape is perturbed to compensate for the transmit pattern shaping. The net result (Figure 3c) has the desired property.

2.2 Implementation

While the "zoom" action can be implemented in several ways, the antenna configuration shown in Figure 4 is the recommended one. The multiple beam
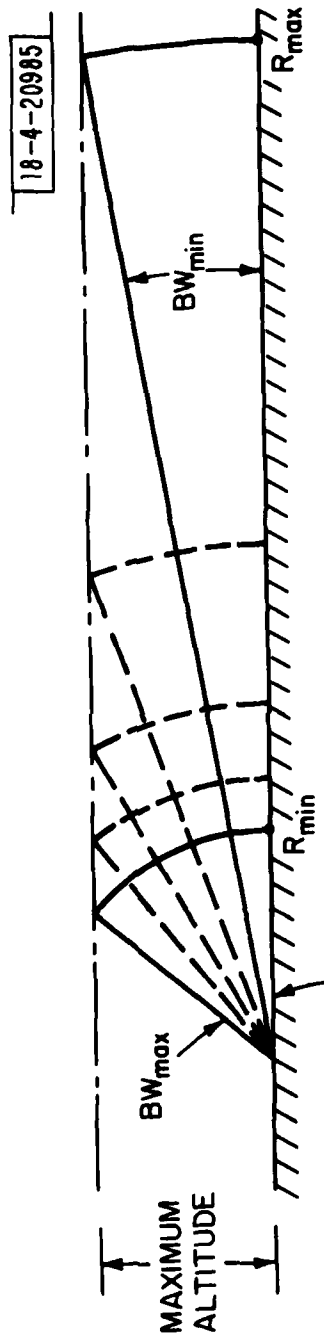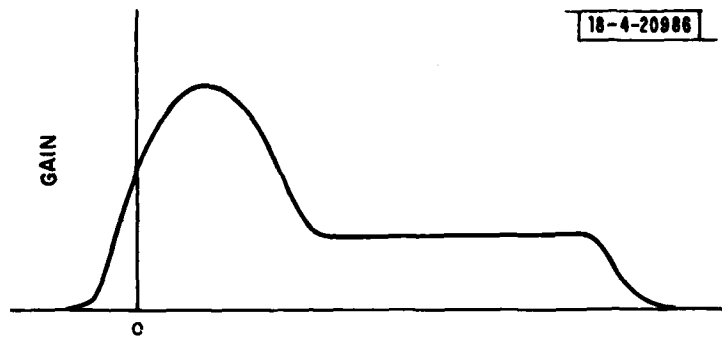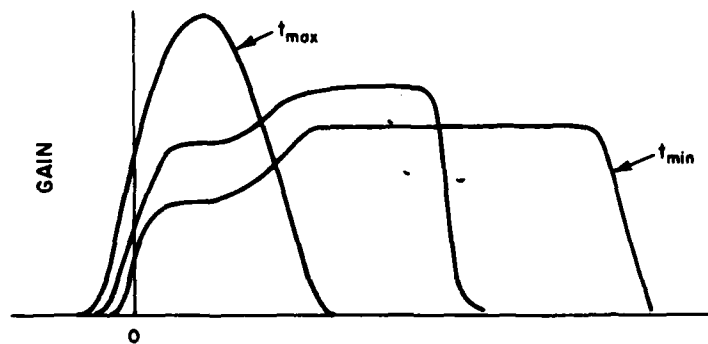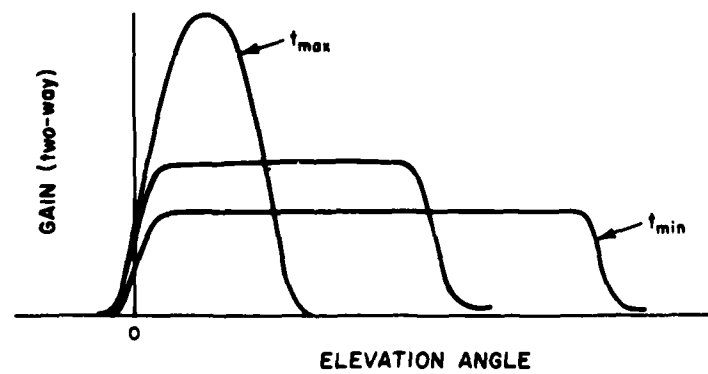
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Fig. 2. Optimized coverage (zoom).

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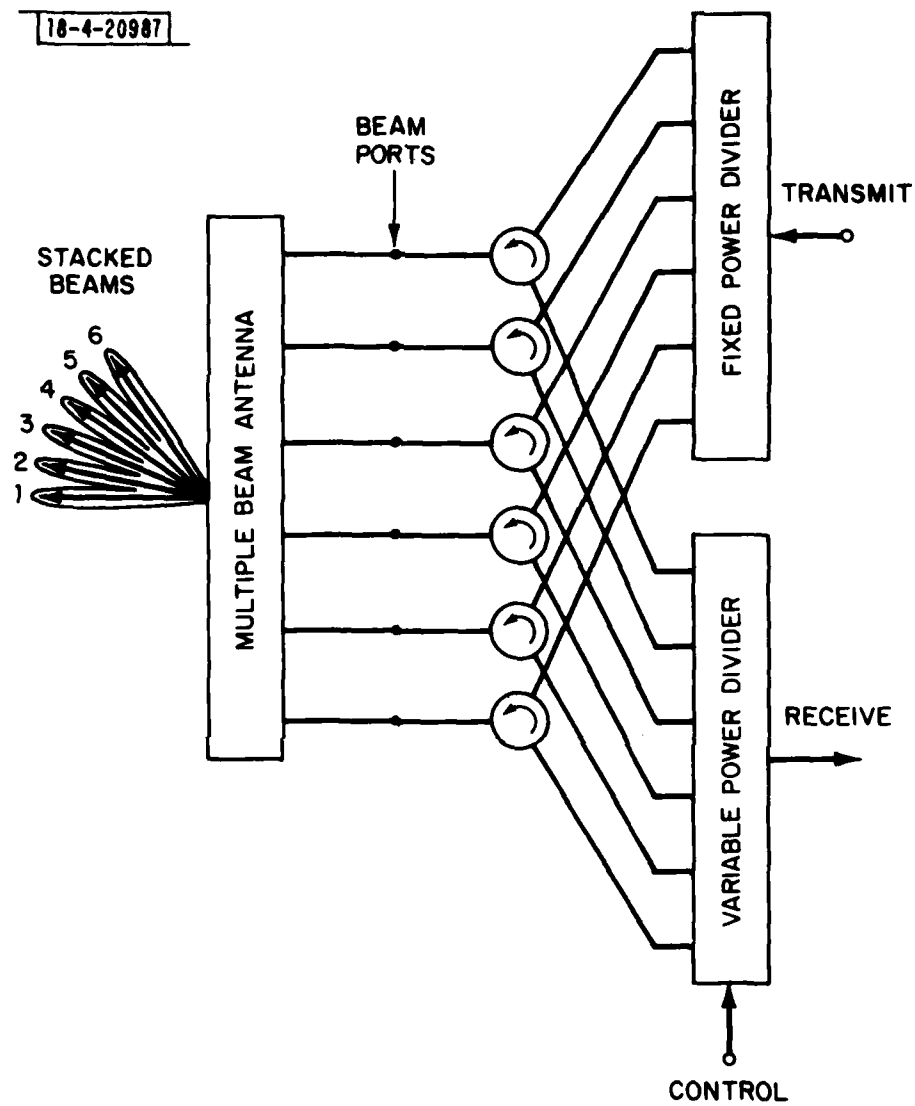Fig. 3(a-c). Synthesis of zoomed patterns.

Fig. 4. Multiple beam zoom antenna.

system guarantees a high rate of underside role-off while minimizing
the number of ports to be controlled, commensurate with the gain and coverage
requirements. Separate duplexed-transmit and receive-combining networks per-
mit the optimization of each pattern while sharing the same beam-forming
structure. The transmit-combining network must be capable of handling high
power; since it is fixed, hence devoid of control elements, this does not
generally represent a problem. The receive combining network is a variable
power divider and hence contains control elements. Fortunately it is called
upon to handle only low power signals; this facilitates the implementation
problem which is characterized by two basic requirements, i.e., fast switching
and low insertion loss. Several techniques are available for the implemen-
tation of a variable power divider. The most straightforward uses the two-port
variable combiner shown in Figure 5 as the basic building block. Note that
depending on the number of discrete steps used to approximate continuously
variable beamwidth, some significant simplifications to the variable power
divider can result. For example, in a good many cases a two-step (three
states) approximation is sufficient; in this case the control elements might
be most simply implemented as switches rather than multi-state phase shifters.
This design optimization should be performed for each design and as such its
detailed treatment is beyond the scope of this report.

3.0 APPLICATION TO S-BAND ASR

The intent of this discussion below is to provide some perspective on the
implementation of the zoom feature. The design is illustrative only, but could
be used as the foundation of a more formal design specification.

Current ASR's operate at S-band (2.7 to 2.9 GHz) and use spoiled para-
boloidal reflectors which are nominally 17 ft. wide by 9 ft. high. An un-
spoiled reflector 17 ft. wide by 5 ft. high, fed by a vertically-stacked feed
horn array, is adequate to support the zoom feature while maintaining the same
basic capability as current antennas. To minimize feed blocking, an offset
configuration such as the one shown on Figure 6 is recommended. Based on the
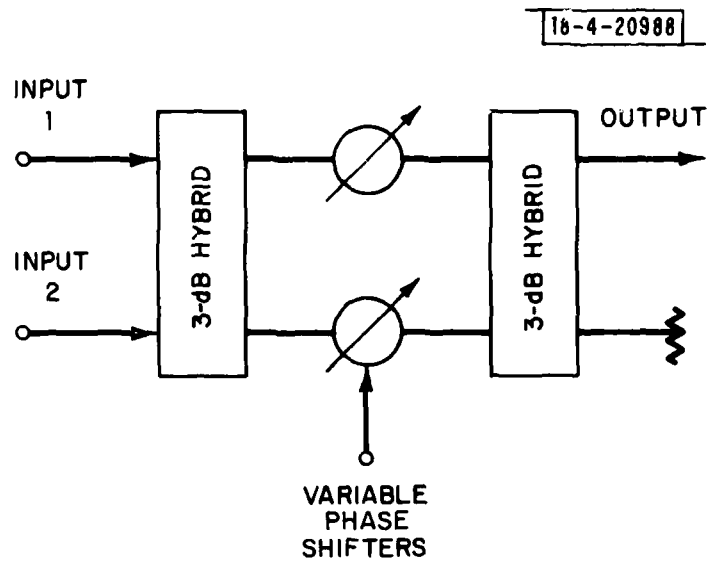results of simplified computations (scalar diffraction) it appears that

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INPUT
1

INPUT
2

3-dB HYBRID

VARIABLE
PHASE
SHIFTERS

3-dB HYBRID

OUTPUT

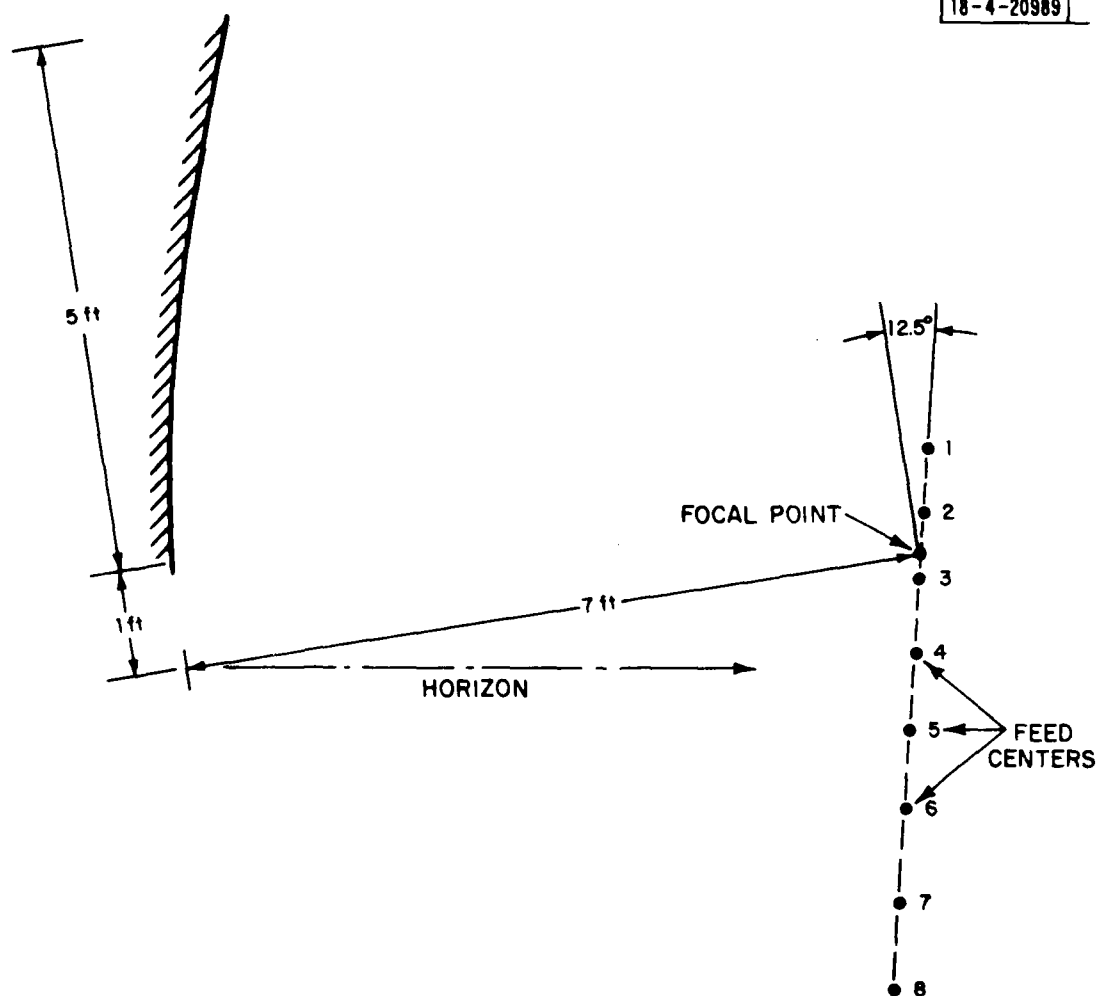Fig. 5.   Variable power combiner.

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Fig. 6. Off-set feed multiple-beam reflector.

feed locations can be found for which the off-axis abberations of the reflector are tolerable. This is demonstrated on Figures 7 and 8 which show the principal plane elevation and azimuth patterns for beams corresponding to individual feeds.

The next step in the design process is the selection of a transmit elevation beam pattern. A basic trade-off exists between the peak gain and the flatness of the pattern over the desired coverage. In the example shown on Figure 9, the pattern levels out at high angles to about -10 dB. This represents a loss of 2.5 dB over the maximum which could be extracted from the aperture and 0.5 to 1.0 dB more than a conventional "cosecant'squared" design. Azimuth patterns are shown on Figure 10 for various elevation angles and appear to be acceptable.

An example of the achievable "zoomed" effect was computed for the three-state receiver power combining network shown in Figure 11. The receiver patterns are synthesized as follows: For long ranges only component beam #1 is used, for medium ranges beams 1, 2 and 3 are used and at short ranges all beams are used. The relative excitation of each receiver component beam was chosen to be the inverse of its transmit coefficient as a first-order approximation to flat top two-way patterns.

The three resulting two-way patterns are shown on Figure 12. Even though these represent only a two-step approximation to the total continuous zoom feature, they are typically adequate in the sense that it is possible to define three range segments over which each beam has an adequate absolute gain while providing constant gain vs. altitude. This is explicitly demonstrated by the range/altitude coverage diagrams shown on Figure 13. It has been assumed that the system sensitivity was such as to provide a 50-mile range with the long-range beam. Note that in this example, the short-range beam could be used inside of 20 miles where STC could be used to maintain nearly constant sensitivity and not suffer any loss of altitude coverage.

One of the key components for successful zoom operation is a phase shifter (or switch) which can change state at a time which is a fraction of a range gate. This is required to minimize the amount of data contaminated by
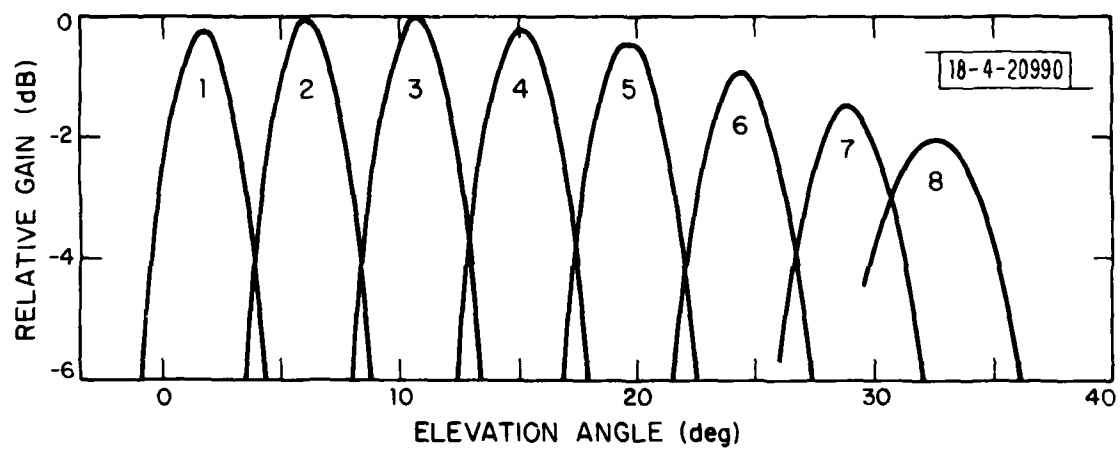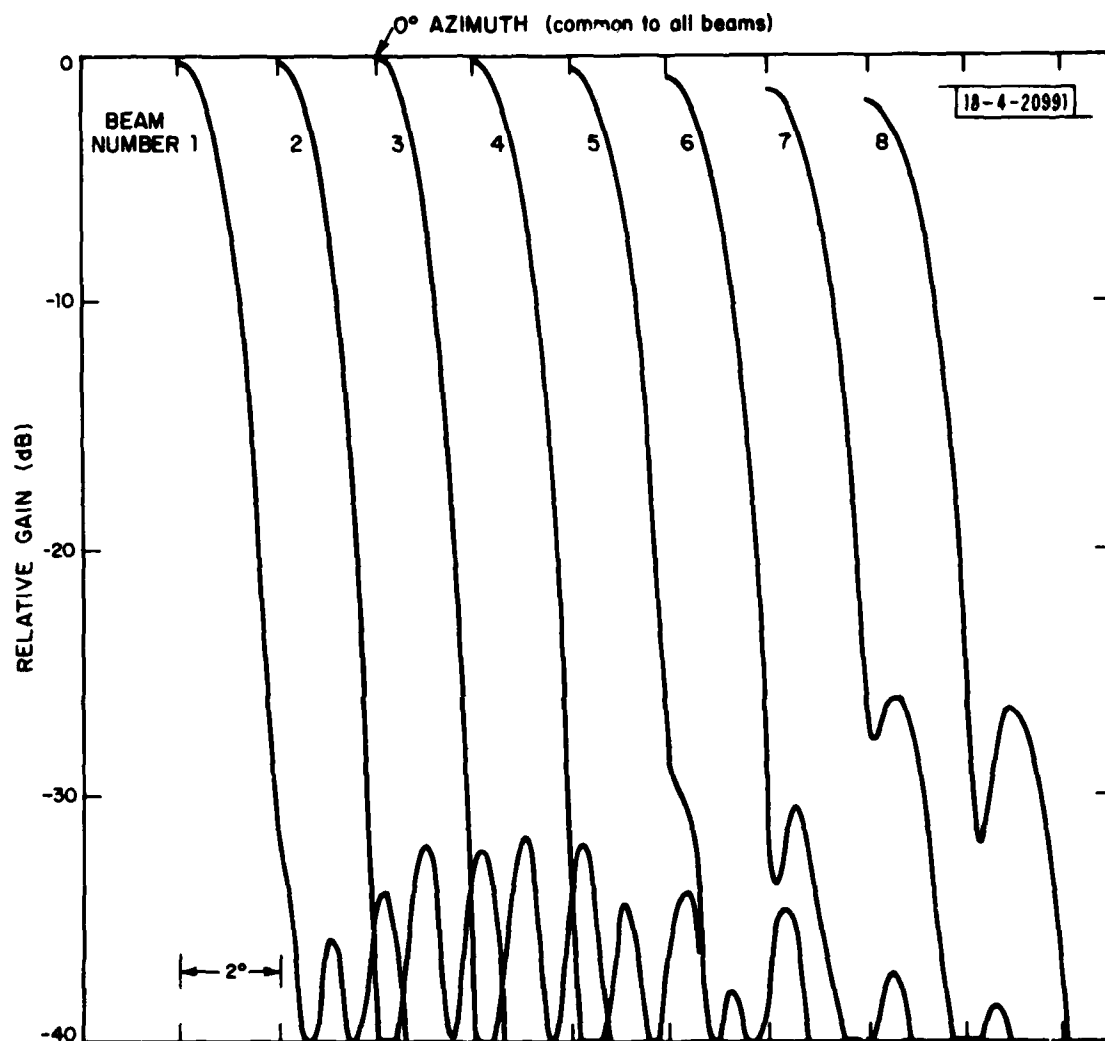
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Fig. 7. Component beams elevation patterns.
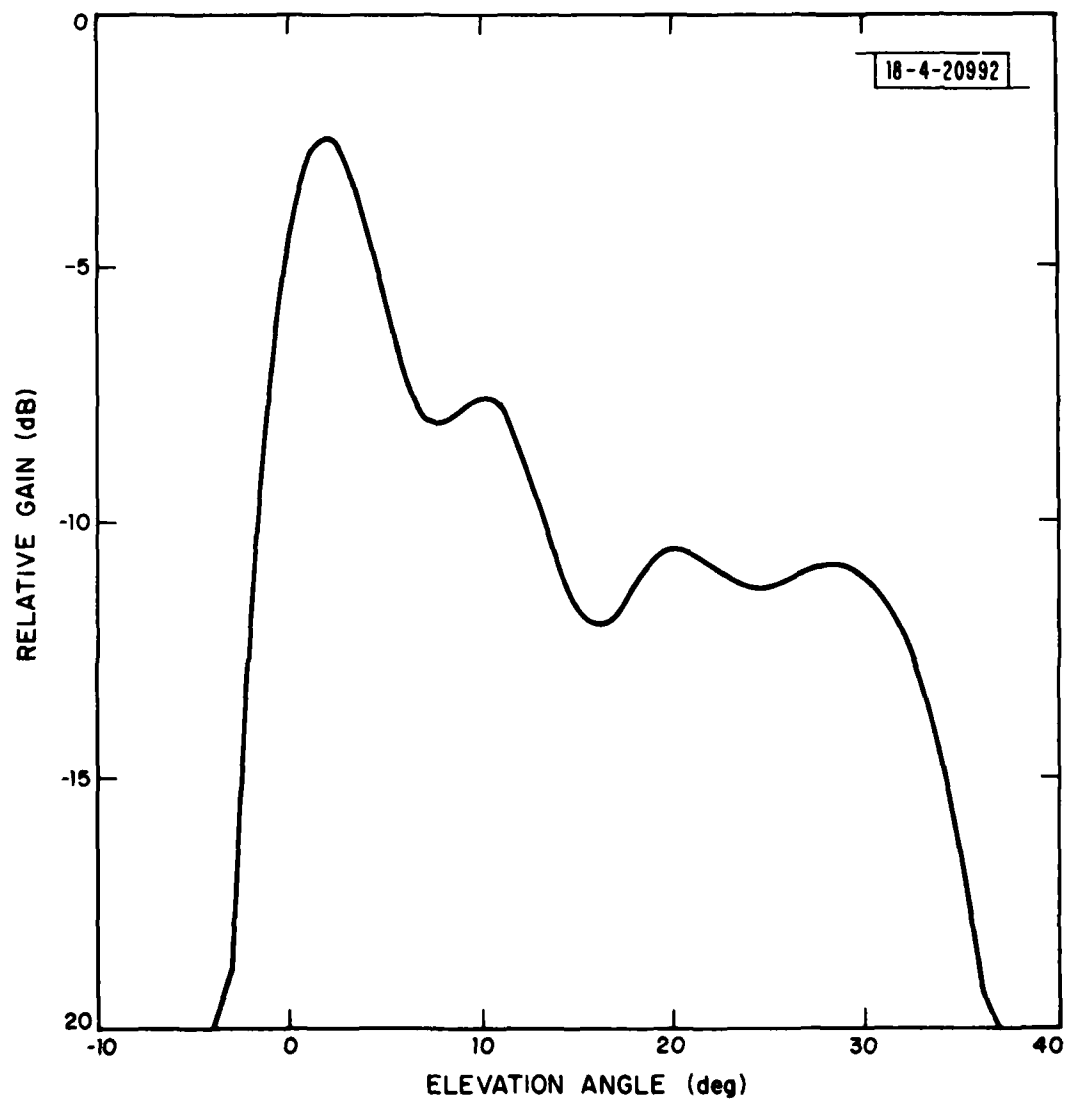
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Fig. 8. Component beams azimuth patterns.
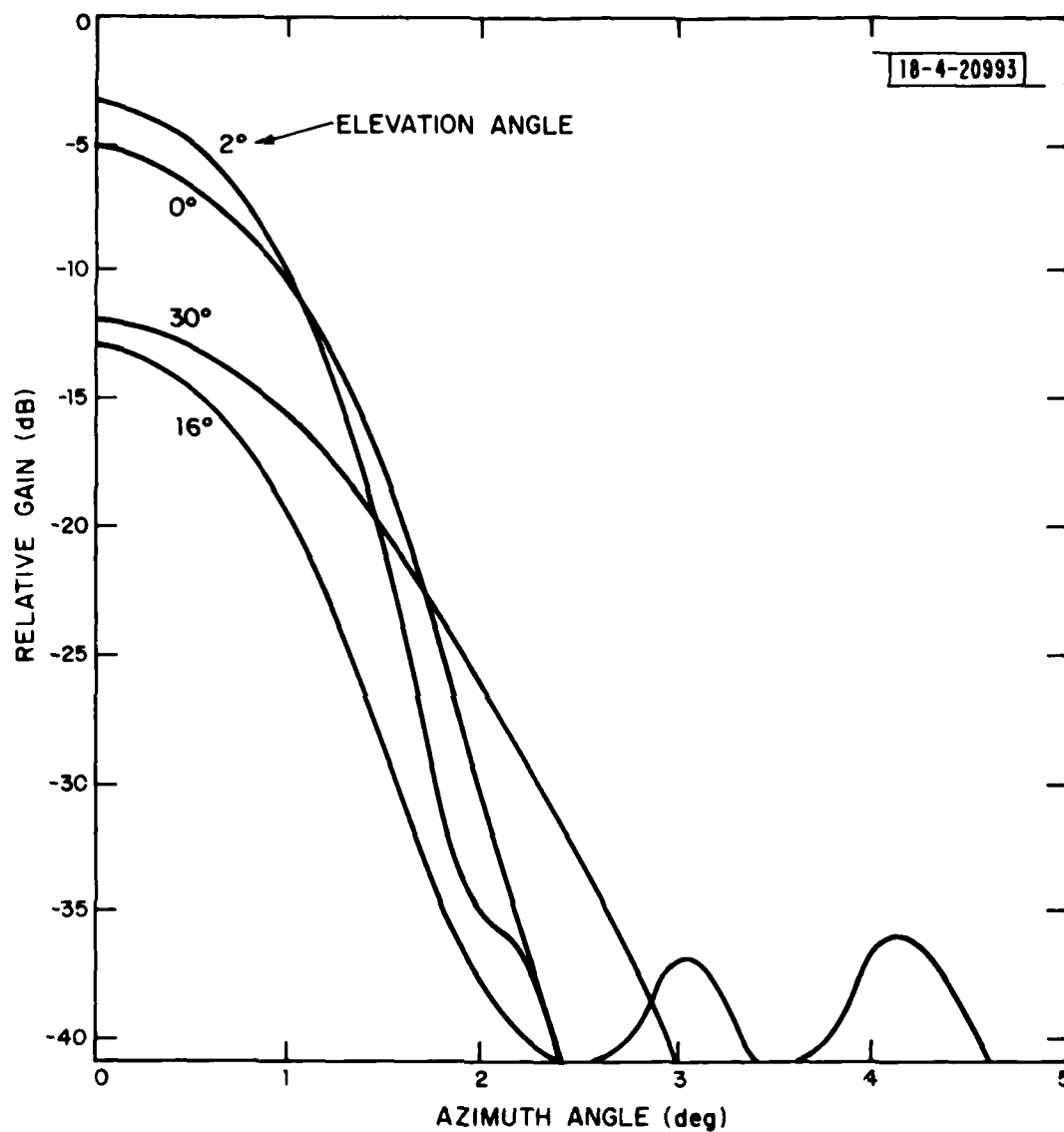
Fig. 9.   Transmit beam elevation pattern.

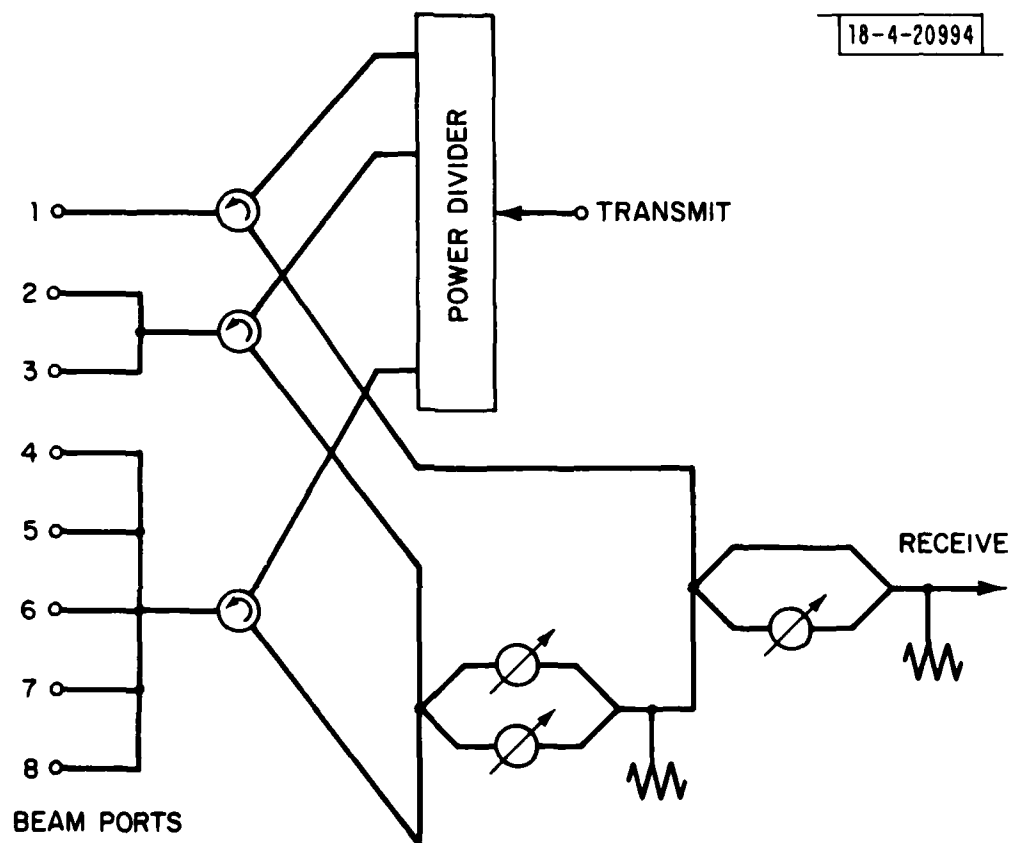Fig. 10. Transmit beam azimuth pattern.

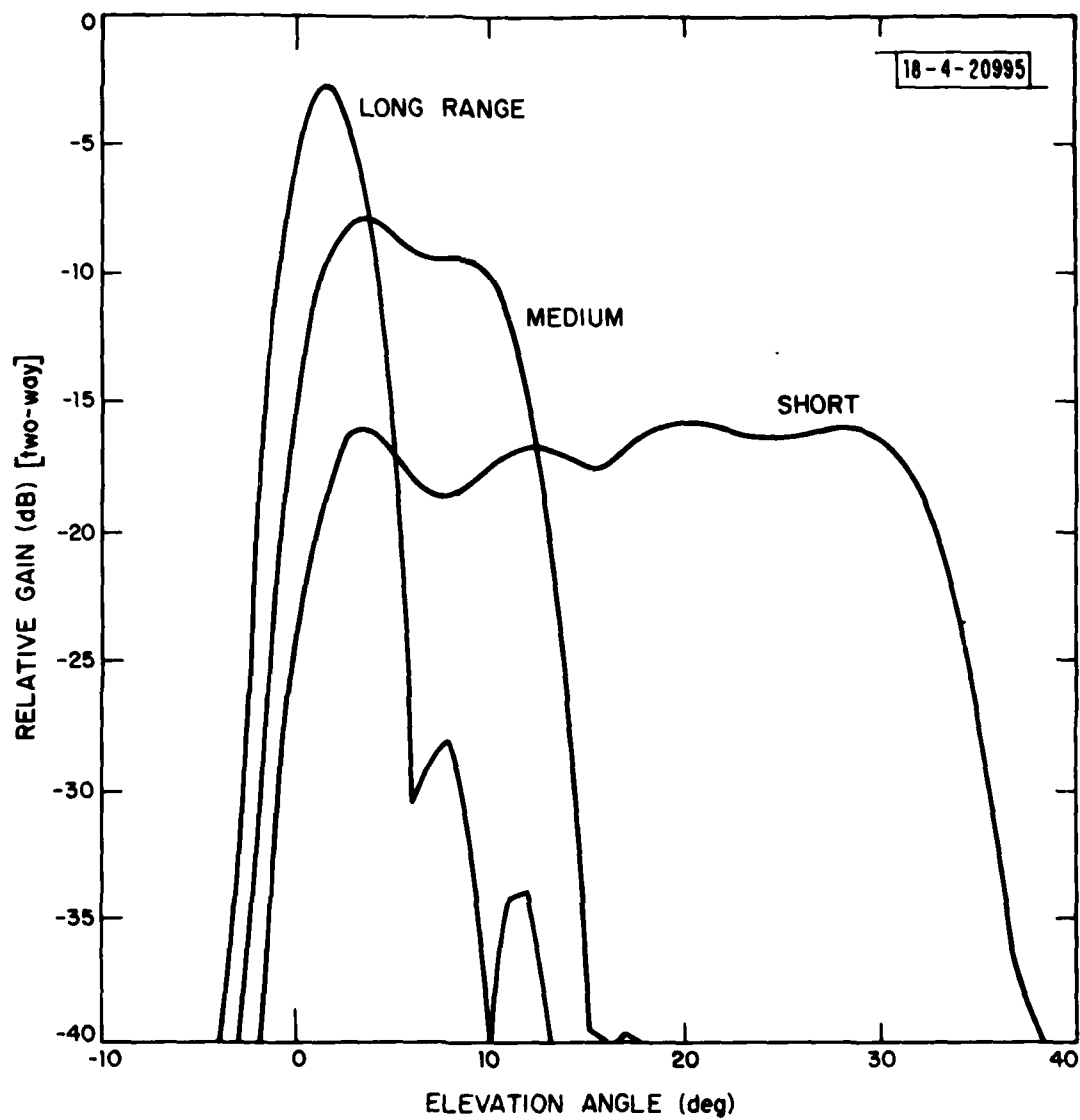14

Fig. 11.   Three state feed network.
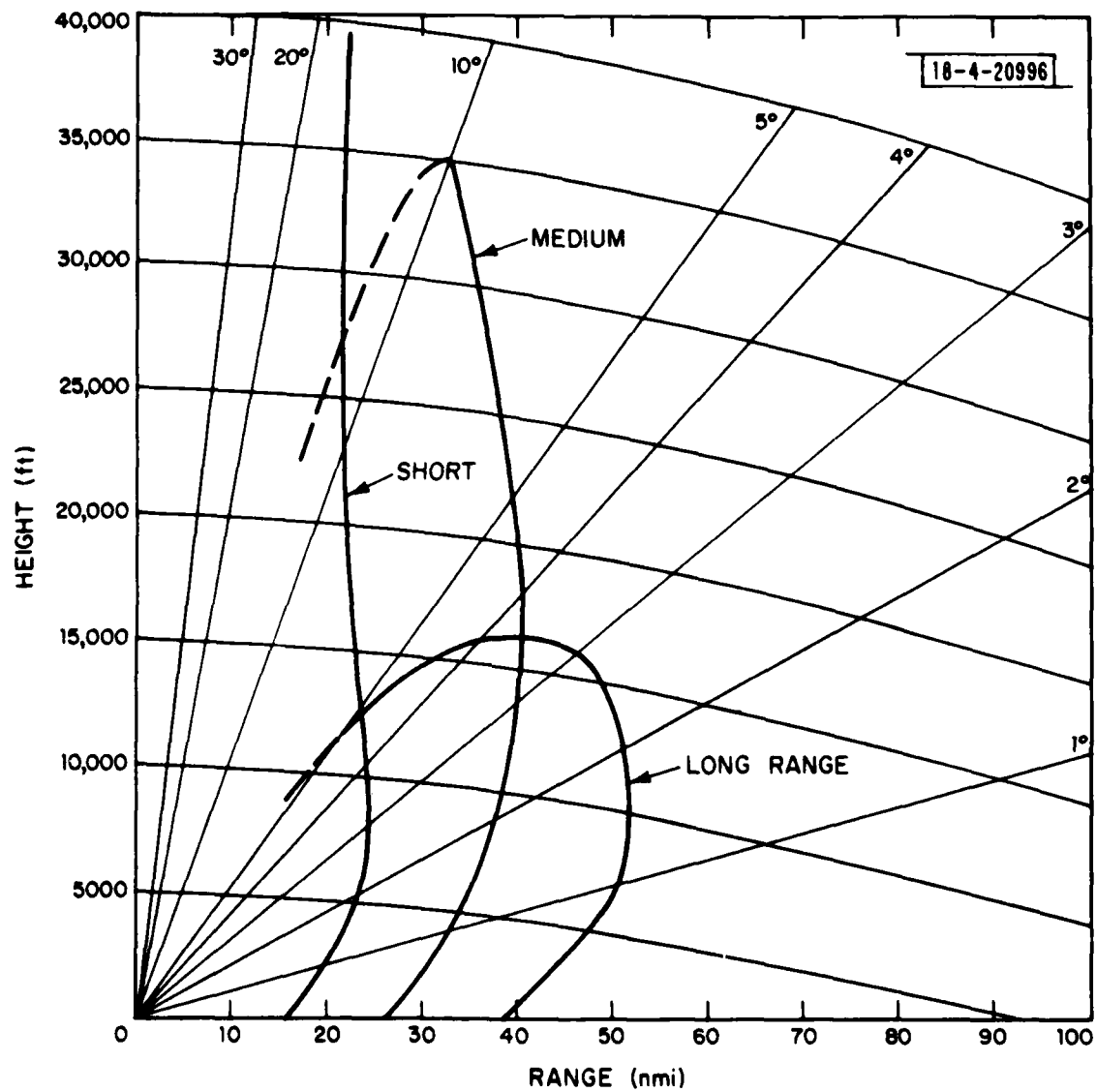
Fig. 12.   Two-way elevation patterns.

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Fig. 13. Range/altitude coverage diagrams.

transient effects (see Section 5 for further discussion). A demonstration
phase shifter was implemented by Microwave Associates. The essential char-
acteristics of the device are given in Table 1. An optimized design for the
receiver combining network, should strive to minimize the loss in the long-
range conditions. Also note that it is desirable for the phase shifters to
survive the leakage transmit pulse energy, thereby avoiding the need for
additional T/R switches; the demonstration unit seemed adequate.

4.0 APPLICATION TO L-BAND RADAR/BEACON ANTENNA

There has been, from time to time, some interest in a combined radar/
beacon antenna where the radar is itself at L-band as is the case for the
Air Route Surveillance Radars. The current ARSR-3 is an example of such
a configuration in which a spoiled paraboidal reflector is shared by radar
and beacon feeds.

The inclusion of the zoom feature for such a system again implies the
use of an unspoiled reflector, about half the height of the current one, a
stacked feed array to generate the multitude component beams, and separate
transmit and variable receive power dividers for radar. The design process
and issues are the same as that for the S-band radar previously discussed.

With radar operating in horizontal polarization it would when be possible
to implement the vertically-polarized beacon feed as an interleaved stacked
array. This would result in a beacon elevation pattern with a high underside
cutoff, as determined by the reflector's full height, and an upper coverage
shaped independently of the radar's by tailoring the beacon feed array's own
vertical power combiner.

5.0 DISCUSSION

The inclusion of the zoom features in any radar system has some clearly
identifiable consequences on the implementation. A number of antenna design
optimization issues have been briefly examined in this report and would need
to be examined in detail as part of a development process. On the other hand,
some issues of a system nature need to be examined in more depth before

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TABLE 1

FAST-SWITCHING PHASE SHIFTER CHARACTERISTICS

(From Microwave Associates)

Number of Bits:	4
Insertion Loss:	1.15 $\pm$ 0.4 dB
Switching Time:	20 nanosec max
Reverse Bias Power Handling:	1 kw (at -30v)

commitment to implementation is made. For one, there is the issue of the
impact of the step discontinuities in the elevation pattern. This is relevant
when the detection threshold in one range cell is determined by levels in
neighboring cells (CFAR processors). Clearly this process is somewhat cor-
rupted in the vicinity of beam switch-over points. This problem is alleviated
by increasing the number of steps in the zoom action. However, as the number
of steps increases so does the number of transient time increments. It is not
clear that the information collected during the phase shifter transition from
one state to another is usable. This is especially crucial for processors in
which groups of pulses are coherently integrated. Is it, in fact, necessary
to blank each range gate during which a transition has occured? The experience
with systems equipped with a "passive" horn should provide a partial answer
to that question. The impact of transition on the integrity of the receive
signal is particularly significant when pulse compression is used since there
is the potential for contamination of several range gates at a time.

The aim of the above remarks has been to alert the reader that while the
"zoom" technique appears effective, practical and possibly cost-effective
from a purely antenna viewpoint, a number of systems related issues, for
which there is little existing experience, need to be examined.